

CRYOGENIC ENGINEERING, PRODUCTION AND USE OF INDUSTRIAL GASES, VACUUM ENGINEERING

THE FIRST EXPERIENCE IN RUSSIA OF USING COAL METHANE IN POWER PLANT HAVING STIRLING ENGINE

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The experience of development and tests of the world's first container-type power plant having a Stirling engine operating on coal methane has been generalized. An analysis has been made of the prospects of Russia's coal regions for producing coal methane as well as of the various technologies of coal methane utilization for electric power and heat generation. The prospects of use for these purposes of power plants having Stirling engines have been substantiated. Full-scale tests of the original design of the container (capsule) power plant having a Stirling engine have been performed. A foreign-made engine was used as the Stirling engine. The obtained test data open up enormous possibilities of development of distributed electrical power industry based on power plants having Stirling engines in coal regions of Russia and other countries of the world with utilization of a new alternative type of motor fuel, namely, coal methane.

Coal methane occurring in coal seams is a promising alternative energy source. Coal methane is a high quality and ecologically clean energy carrier, whose combustion heat (calorific value) is as high as 2006 kJ/m^3 , which corresponds to 1.2 kg/m^3 of a conventional fuel. Furthermore, methane is also a feedstock for the chemical industry. On the whole, reserves of coal methane, as estimated by many experts, exceed reserves of natural gas [1].

Economic feasibility of large-scale commercial production of methane from coal seams is supported by experience of development of methane-bearing coal fields in many developed countries, for example in the USA, which occupy the leading place in the world in terms of the level of development of the "new gas industry." In the USA, methane production rose steeply from 5 billion in 1990 to 50 billion cubic meters in 2005, which constituted 8 % of natural gas production. Also, Australia, Canada, China, and Colombia have also been extracting methane from coal seams.

As estimated by Gazprom company, the predicted reserves of methane in coal seams are equivalent to proven reserves of natural gas in Russia and comprise 49 trillion cubic meters, i.e., 15 % of the world reserves. Methane reserves in coal seams in Russia range, as reported by various sources, from 100 to 120 billion cubic meters per year, taking account of the reserves in eastern and northeastern coal basins. Today, the volume of gas of methane workings is about $30\text{--}40 \text{ m}^3/\text{ton}$ of coal produced.

At present, the most promising, in terms of methane production, is the Kuznetsk Coal Basin (Kuzbas). In May 2003, Gazprom, Kemerovo Regional Administration, and Kuznetsk Mine-Sinking Combine, presently called Gazprom Dobycha Kuznetsk Company, signed an agreement for implementing a project for commercial coal methane production. Gazprom Dobycha Kuznetsk has a license for exploration and production of methane from coal seams within the bounds of South Kuzbas group of coalfields, which have a reserve of 6.1 trillion cubic meters of methane.

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Fig. 1. Demonstration area for recovery of coal methane by boring coal seams in the Taldinskii test ground.

It is proposed that in a favorable taxation situation and at a high gas price until the year 2020 the volume of coal methane production by Gazprom Dobycha Kuznetsk will be $20 \cdot 10^9 \text{ m}^3/\text{yr}$. This production volume can be achieved from the Kemerovo, Novosibirsk, and Omsk regions as well as from the Altai Territory.

Within the framework of the first stage of the above-referred agreement, a plan was provided to create an experimental polygon (test ground) for recovery of coal methane by drilling boreholes in coal seams. The Taldinskoye methane-bearing coalfield lying at the center of the Erunakovskii economic geology region of the Kuznetsk Coal Basin in the Novokuznetsk and Prokopyevsk areas of the Kemerovo Region (Fig. 1) was chosen as the demonstration area for developing various advanced technologies.

The method of gas recovery outside the fields of the currently operating mines by drilling special boreholes from the surface using artificial method of raising gas permeability of the coal seams (hydraulic fracturing method) was used as the main method of methane extraction from coal seams. Water pumped under pressure into the gas-bearing coal seam deforms (fractures) the latter. Methane runs into the slit thus formed and is then pumped out.

At present, the Taldinskii experimental polygon (test ground) functions as one of the four boreholes with the required engineering infrastructure.

The major goals of the investigations at the polygon are preliminary and acceptance tests of the pilot prototypes of domestic borehole and aboveground equipment and convert methane resources into commercial-category reserves. This is associated with the fact that for a long time lack of the requisite informative documents and preferences (priorities) hindered commercial production of coal methane in Russia. Recently, the Ministry of Natural Resources and Ecology of the Russian Federation approved the decision of the State Commission on Mineral Resources (GKZ Rosnedra) to put in the State Assets Balance $44.8 \cdot 10^9 \text{ m}^3$ of methane resources per year in coal seams of the Taldinskoye methane-bearing coalfield in the Kemerovo Region. The Russian Geological Foundation (Rosgeolfond) has been recommended to take account of the proven methane resources of this field in terms of $C_1 + C_2$ gas categories. In other words, coal methane is recognized in Russia as an independent fossil fuel.

It must be noted however that until 2008 coal methane recovered at the Taldinskii polygon had been simply burned off in flares because there was practically no technology in Russia for utilizing coal methane.

Utilization of coal methane in power plants using Stirling engine is a promising line of development of independent power supply in coal regions of Russia.

Coal methane is used abroad for power generation, water and air heating in mines, heating of industrial and residential premises by burning it in boilers, coal drying plants, etc., and also as motor fuel.

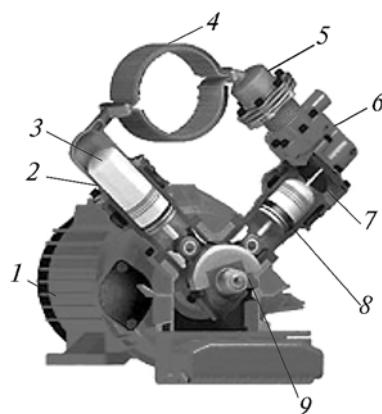


Fig. 2. Assembly scheme of Stirling engine: 1) generator; 2) cylinder of expansion chamber; 3) plunger; 4) heater; 5) regenerator; 6) cooler; 7) working piston; 8) cylinder of compression chamber; 9) crankshaft.

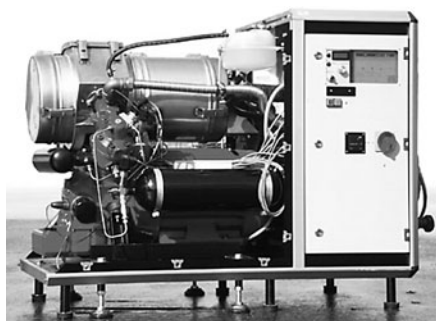


Fig. 3. Cogenerative plant SOLO Stirling 161 CHP.

Currently, coal methane is used very widely for power generation. More than 70 power plants have been built in Australia, China, Germany, Poland, Britain, Ukraine, and the USA. The total capacity of the power plants utilizing coal methane is about 400 MW. But for utilizing coal methane, in general, only large-capacity (500 kW and above) power plants are used. Moreover, the designs of these plants are based on gas-piston carburetor engines and diesel internal combustion engines (ICE). This type of engines requires additional coal methane purification systems, maintenance of a constant ratio of the components of the original coal methane, frequent scheduled operations, and installation of additional filters for maintaining ecological standards. All this restricted wide use of coal methane for power generation.

Russian experts believe that power plants based on Stirling engines are the most promising direction of coal methane utilization [2–4]. Stirling machines are an appropriate combination in a single unit of a compressor, an expander, and heat exchanging devices (heater, regenerator, and cooler), which form an internal loop with the working medium that moves between the “cold” part, generally occurring at the ambient temperature, and the “hot” part. Heating of the working medium of the Stirling engine occurs on account of combustion of any type of fuel or utilization of other heat sources. Currently, not only conventional energy carriers (petroleum products, natural gas, etc.) but also solar energy, biogas, wood, peat, coal, etc. are being used widely as heat sources for Stirling engines.

The assembly scheme of the Stirling engine is shown in Fig. 2. The Stirling engine belongs to the class of engines with external heat supply (EEHS). Because of this, unlike ICE, the combustion process in Stirling engines occurs outside the

working cylinders. Stirling engines used for these purposes enjoy unquestionable advantages over ICE from the standpoint of ecology, operating costs, operating life (up to 60000 h), etc., and possibility of remote monitoring and control in a real time scale. Another notable advantage of Stirling engines consists in the possibility of monitoring load variation in a wide range of powers with minimum loss of efficiency.

In 2008, experiments were performed at the Taldinskii polygon to determine the possibility of operation of a cogenerative plant having a Stirling engine operating on coal methane. For these investigations, Russkii Stirling Company developed a unique design of a container-type power plant having a Stirling engine. In the course of execution and realization of the project, complex scientific and technical problems associated with designing of many units of the container (capsule) power plant having a Stirling engine were solved for the first time.

A foreign model of SOLO Stirling 161 CHP cogenerative plant (Fig. 3) was used as the Stirling engine. The electronic control system of the plant makes it possible to control several parameters of the engine, which allow monitoring of the change in heat of combustion of the fuel. In keeping with these changes, the performance of the Stirling engine is adjusted, which ensures its steady operation, regardless of the fuel composition. Because of this, Stirling engines ideally conform to the technology of utilization of coal methane as a motor fuel. Power plants having Stirling engines allow direct utilization of both coal methane from the borehole and captured (piped) mine gas.

The container power plant having a Stirling engine, built as a system in a state of high factory (service) readiness, was delivered from St. Petersburg to the Taldinskii polygon (test ground).

Apart from Russkii Stirling, other St. Petersburg companies, whose experts carried out installation and adjustment of the electrical part (power-generation part) as well as of the automation system of this power plant, also took part in realizing this project.

The results of the performed full-scale tests of the container-type power plant having a Stirling engine open up enormous possibilities of development of a new technology for power generation in coal regions of Russia, which consists in creating independent power supply systems based on Stirling engines that use coal methane as motor fuel.

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